POLARIMETRIC PASSIVE REMOTE SENSING OF THE OCEAN UNDER HIGH WIND CONDITION

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LONG-TERM GOAL

This project investigates the application of fully polarimetric passive remote sensing techniques to the detection of ocean surface wind direction using air-borne or space-borne radiometers. The goals are:

1. Develop and validate a model for the prediction of wind generated ocean surface polarimetric brightness temperature as a function of wind speed and direction; and
2. Use this model for the investigation of wind speed and direction retrieval techniques from passive polarimetric data under a variety of sea surface conditions.

SCIENTIFIC OBJECTIVES

The primary scientific objective of this project is to extend current knowledge of polarimetric passive remote sensing and to assess the response of polarimetric quantities to various environmental parameters. For application to passive remote sensing of the ocean, specific objectives are:

1. Develop models for the accurate prediction of polarimetric thermal emission from randomly rough surfaces. Assess the response of polarimetric quantities to wind speed, direction, temperature, salinity and other ocean physical properties, as well as observing sensor parameters;
2. Study atmospheric effects on measured polarimetric brightnesses, and to determine if atmospheric effects limit the applicability of polarimetric techniques; and
3. Study high wind condition effects, including breaking waves and foams, on measured polarimetric brightnesses and to determine if high wind conditions limit the applicability of polarimetric techniques.

APPROACH

The principal goal of this project is to obtain a better understanding of how the third Stokes brightness parameter, U, is related to ocean wind direction. This brightness parameter, which is not measured in conventional passive remote sensing, has recently been shown to respond to the azimuthal anisotropy of the observed medium and thus should give information on ocean wind direction. The calculation of the polarimetric brightness temperature of the ocean requires the use of rough surface scattering theory and a statistical model of the ocean surface. Our approaches include the use of analytic rough surface scattering theories, such as composite surface scattering

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model, and numerical methods, such as the method of moments. Monte Carlo simulations based on exact numerical methods are used for randomly rough surfaces to insure accurate calculation of the polarimetric brightness temperature.

Experimental verification of our models is an important part of the process. The growing interest in polarimetric passive remote sensing of the ocean has resulted in a number of ongoing and future experiments in which we plan to participate and compare our model results with the experimental results. The use of polarimetric passive techniques for ocean remote sensing from a realistic satellite borne radiometer will be studied. Atmospheric effects on the measurements will be investigated using radiative transfer theory, and other potential effects, such as breaking waves and foams under high wind conditions, will also be studied. a variety of retrieval techniques for wind speed and direction from polarimetric passive data will be examined to determine the most advantageous sensor configuration and retrieval method.

WORK COMPLETED

The results of this project to date are favorable for the application of polarimetric techniques in future air- or space-borne passive sensors. Theories and experiments involving one dimensional periodic surfaces have demonstrated that U responds to surface azimuthal anisotropy. These results indicate that use of U can enhance retrieval techniques for physical properties of azimuthally asymmetric media.

Models for prediction of polarimetric brightness temperatures of one and two dimensional periodic surfaces have been developed and applied in theoretical studies. Properties of U for one dimensional surfaces have been examined through both theory and experiments. Figure 1 illustrates the X band U return from a periodic water surface as a function of azimuthal observation angle at a polar angle of 20 degrees. A comprehensive paper describing this theory and experiment won the 1993 best paper award from the IEEE Geoscience and Remote Sensing Society (Johnson, et al., 1993). A study of two dimensional periodic pyramidal surface polarimetric thermal emission has indicated that properties of U observed in the one dimensional surfacecase remain similar for two dimensional surfaces. Furthermore, a study of the response of U to the level of medium anisotropy was performed, and it was found that the U brightness temperature saturates relatively quickly as azimuthal anisotropy increases.

Models for prediction of polarimetric brightness temperatures of one and two dimensional randomly rough surfaces have been developed and applied in Monte Carlo simulations of ocean-like surfaces. Sensitivities of polarimetric brightnesses to various ocean properties have been investigated. Monte Carlo simulations of one dimensional randomly rough surfaces have demonstrated that U again responds to surface azimuthal anisotropy, and that U is insensitive to the polar angle of observation and to the permittivity of ocean-like surfaces at Ku band. However, the magnitude of the U return from ocean-like surfaces was observed to be small (less than 5 K). Thus, although U has desirable properties for air or space borne passive ocean remote sensing, sensitive radiometers must be employed to insure accurate measurements. This same Monte Carlo model has been validated through comparison with bistatic scattering measurements of fabricated very rough two dimensional Gaussian surfaces as shown in Figure 2. This comparison demonstrates that the model currently being applied for prediction of realistic ocean surface polarimetric brightnesses should give accurate results.

A model for the prediction of polarimetric brightness temperatures of foam or spray patches covered ocean surface under high wind conditions has been developed. The foam cover is modeled as a layer of randomly distributed spherical water droplets overlying the wind-driven ocean surface. The ocean surface is characterized by an empirical power spectrum density. Radiative transfer theory is applied to calculate the fully polarimetric brightness temperatures. The small perturbation method is used to compute the scattering from rough ocean surface. The effect of coupled volume and surface interaction on the polarimetric thermal emissions from foam covered ocean surface is taken into account. Theoreticl predictions of this model are compared with the empirical expressions for the foam layer emissivity and the WINDRAD experimental data from JPL. A good agreement has been achieved as shown in Figure 3. The results indicate the important contribution of the volume scattering of foam layer to the brightness temperatures Tv and Th, and the effects of anisotropic ocean surface on the third Stokes parameter U.

IMPACT/APPLICATION

The positive results of this project to date are expected to generate further interest in polarimetric techniques for passive remote sensing and to lead to the development of future polarimetric passive systems for Earth remote sensing. Application of polarimetric techniques in passive remote sensing of the ocean has shown potential for more accurate space-borne measurements of global wind vectors in the future. In addition, the surface scattering models developed in this project can also be applied in other studies of rough surface scattering, including studies of active remote sensing of the ocean, and should provide very accurate predictions by which the validity of other approximate methods can be assessed. A better understanding of rough surface scattering phenomenology should result, as well as the potential development of future extended analytical theories.

TRANSITIONS

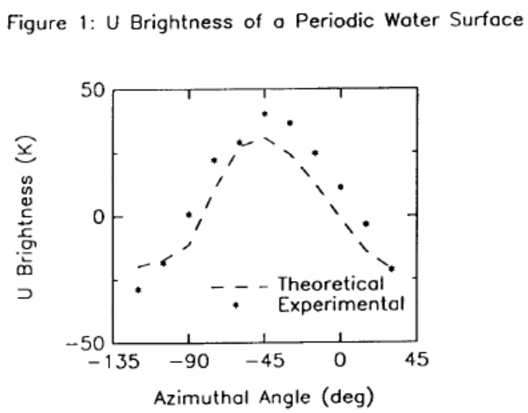
The project is currently in a state of transition from early research, which focused on using simple models to assess general properties of polarimetric parameters, to current research which focuses on more realistic models for the specific case of ocean passive remote sensing. Inclusion of an ocean spectrum model from the literature, as well as the effects of breaking waves and foams, are currently under investigation to create a very accurate simulation of the ocean environment. Transitions beyond this phase involve an assessment of specific sensor systems and retrieval techniques for obtaining maximum utility from polarimetric measurements. In addition, comparisons with measurements will be made continuously as more experimental data becomes available.

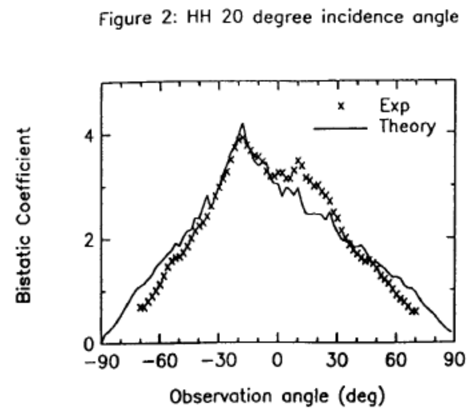
RELATED PROJECTS

The results of this project can be applied in any other programs which involve passive remote sensing of the ocean. Since quantities used in conventional passive remote sensing are also measured in polarimetric passive remote sensing, the models developed in the project can also be used to assess the performance of conventional passive sensor systems. Also, as mentioned previously, the surface scattering models developed in this project can be applied in other programs which involve active remote sensing of the ocean.

REFERENCES

Johnson, J.T., J.A. Kong, R.T. Shin, D.H. Staelin, K. O'Neil, and A. Lohanick, 1993. "Third Stokes parameter Emission from a Periodic Water Surface," IEEE Trans. Geosci. Remote Sensing, Vol. 31, pp. 1066-1080.





Figures 1 and 2. Brightness of a Periodic Water Surface and HH 20 degree Incidence Angle, respectively

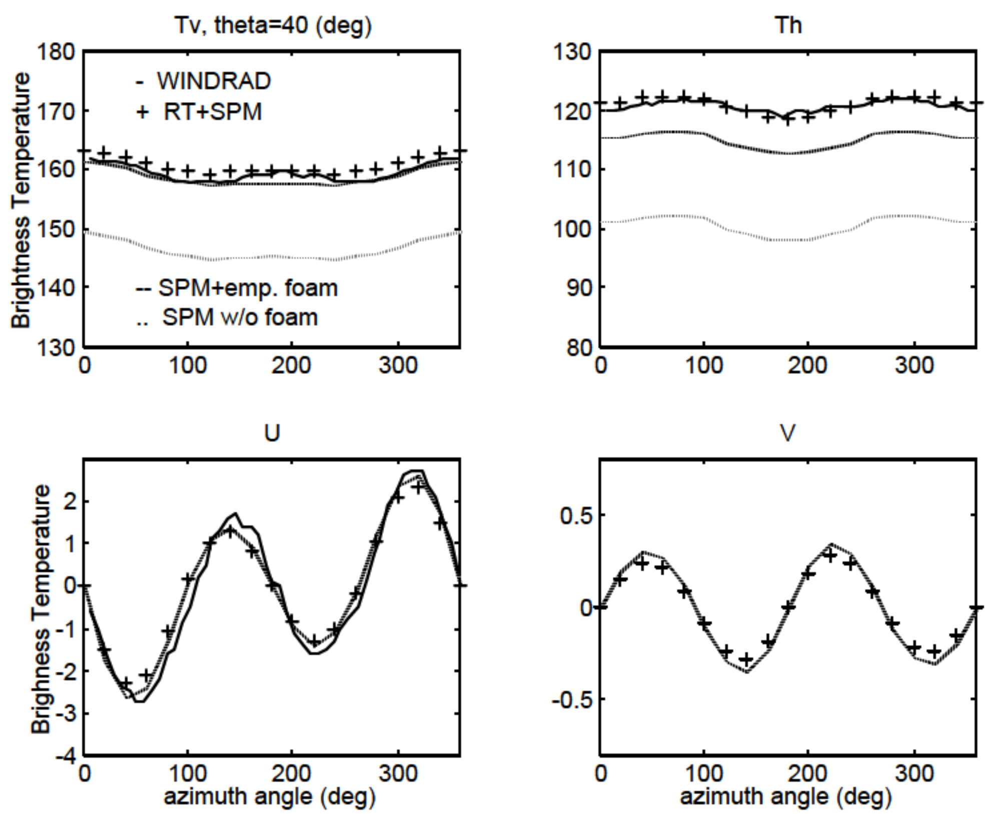


Figure 3. Brightness Temperatures of Wind-driven Ocean Surface in the Function of Azimuthal Angle.

The nadir looking angle is $40°$. The physical temperature of ocean water is $10° C$ and the salinity is 3.5%. The wind speed is $12(m/s)$, and the azimuth angle is defined to be zero in the direction of wind speed. The solid line indicates the WINDRAD experimental data. The cross "+", illustrates the simulation results by solving RT equation with rough surface. The dot line ".." indicates the simulation result only considering the rough surface using SPM. The dashed line "--" is the results by adding an empirical foam contribution on the dot line.